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PROCEDURES USED TO GENERATE THREE- AND SIX-YEAR-OLD-CHILD DATA SETS FOR THE ARTICULATED TOTAL BODY MODEL FROM ANTHROPOMETRIC DATA

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ABSTRACT

A class of rigid component, chained system models has been developed to predict relative limb and whole body motion of humans during vehicle crashes and aircraft ejection situations. Members of this class include the 3-D Crash Victim Simulator and the Articulated Total Body Model. Both have similar input data requirements, including individual segment inertial properties, joint locations and their biomechanical characteristics, and contact surface definitions. Currently, the only body class for which a significant amount of such data exist is the adult male. In this paper state-of-the-art techniques are presented for generating ATB Model input data sets for two other body classes, the three- and six-year-old child, from anthropometric data. The anthropometric data on these two classes are unique because dental stone manikins have been developed from them that provide various direct inertia and dimensional data for comparison with the corresponding values developed using these techniques.

1. INTRODUCTION AND SUMMARY

Protection of passengers from injury during vehicle and aircraft crashes and the protection of a crew from injury during aircraft ejection situations is one of the important design objectives of vehicle and aircraft design engineers. An increasingly important tool in evaluating the safety aspects of different designs is computer software simulation. Calspan Corporation has developed a particularly sophisticated class of these programs. The class includes the 3-D Crash Victim Simulator (CVS) Model, developed under DOT sponsorship (Fleck, et al, 1974), and the Articulated Total Body (ATB) Model, developed from the CVS Model under the sponsorship of the U.S. Air Force Aerospace Medical Research Laboratories (AMRL) specifically for application to aerospace-type problems (Fleck and Butler, 1975). These programs model the human (or laboratory animal) body as a multi-segment chained system. Currently 15 segments are defined: head, neck, upper arm (left and right), lower arm (left and right; includes the hand), upper torso (thoracic region), middle torso (viscera), lower torso (pelvic region), upper leg (left and right), lower leg (left and right), and foot (left and right).

Among the input data required on each segment are:

- inertia properties (mass, center of mass, principal moments, principal axes orientation)
- ellipsoid dimensions, axes origin with respect to the center of mass, and axes orientation with respect to the principal axes
- joint locations with respect to the center of mass, and joint axes orientation (Each joint has two sets of axes, one for each segment associated with the joint. These axes are used to define torques at the joint.)
- various joint stiffness and friction constants

In addition, data must be supplied to define the initial orientation of the body with respect to an external reference coordinate system. The environment (contact planes, restraint systems) must also be defined, as well as remaining initial conditions and the external stimuli to be applied to the system.

The program simulates the dynamics of body motion using a unique method that has been shown to be equivalent to the Lagrange method. Motion picture films of the dynamics can be produced through the use of plot packages supplied with the simulation program.

The University of Dayton Research Institute (UDRI), under the sponsorship of AMRL, is currently involved in a research program to develop input data sets for the ATB Model program. This paper surveys techniques recently developed by the UDRI for obtaining the segment inertia, joint location, and contact ellipsoid data and the initial body orientation. The most direct measurement techniques available for obtaining the segment data involve the use of anthropometric data to define the dimensions of geometric models approximating body segment geometry. The geometric solids, in appropriate combination, have been incorporated into computer programs that generate the required data.

This paper is organized into three parts. Techniques used to generate ATB Model input data sets for 3-year-old and 6-year-old children from anthropometric data are discussed in Section 2.

(Due to their volume, the actual input data sets are not published here. They can be obtained from the author or AMRL.) Some more advanced techniques and programs, still in the development stage, are described in Section 3. The last section discusses directions future efforts are likely to follow.

2. TECHNIQUES USED TO GENERATE ATB MODEL INPUT DATA SETS FOR THE THREE- AND SIX-YEAR-OLD CHILD

The Available Anthropometric Data

The development of ATB Model input data set preparation techniques has emphasized the preparation of data sets for the average three- and six-year-old-child. There are two reasons for emphasing these body classes. The first reason is that these data are needed by the Department of Transportation for auto crash air bag studies. The second is that two anthropometric studies have recently been published that provide detailed anthropometric, inertial and joint location data that can be used to evaluate the data set preparation techniques being developed. One of these studies, performed by Snyder, et al (1977) at the Highway Safety Research Institute (HSRI) under the sponsorship of the Consumer Product Safety Commission, used the latest in automated equipment to obtain and statistically analyze a large sample of standard anthropometric measurements for infants, children, and youths up to age 19. The data are organized by age, are up-to-date, accurate to the state-of-the-art, and copious. The other study was performed by Young, et al (1976) at the Civil Aeromedical Institute under the sponsorship of the Office of Aviation Medicine. In this study, two full-scale dental stone manikins of the average three-year-old and six-year-old were constructed. A number of standard anthropometric measurements available in the literature, along with some nonstandard measurements, were used to construct the manikins. They were constructed in a standard sitting position (to be described later in this paper) and front, side, and rear photographs taken with a ruler scale in view to allow direct determination of dimensions from the photographs. The manikins were segmented and estimates of the centers of mass and some principal moments were made for the segments. Data were also obtained on joints and other landmark locations and specified with respect to each segment's center of mass.

Techniques Used to Generate the Inertia Data

Previous body segment geometric models have been approximated as homogeneous ellipsoids, cylinders, or frustrums of circular cones. The geometric model chosen for our initial modeling effort was a more general shape, a homogeneous right elliptical solid, which has these characteristics:

- It has two parallel elliptical end-planes. A z-axis is defined through the centroids of these end-planes and is normal to both planes.
- The end-planes and any other cross-section parallel to them are ellipses with centers on the z-axis and semiaxes in the xz- or yz-planes.

For our purposes, the shapes of the right elliptical solids to be considered are further restricted to those that can be defined by supplying the semiaxis values of the end-planes and a single cross-section somewhere between the end-planes. Although the other geometric models mentioned have the advantage of having existing closed form expressions for their inertia properties, they are relatively poor approximations to the actual body shape when compared to the right elliptical solids described here.

A very fast interactive FORTRAN program called MISEC2 has been written to compute the inertia properties of the homogeneous right elliptical solid described (Leet, 1978a). The program approximates the solid as a stack of elliptical cylinders of varying semiaxis values, computes the inertia properties of each cylinder, computes the center of mass of the solid as a whole, and then used the parallel axis theorem to shift the individual cylinder's center of rotation to the solid's center of mass, where they are appropriately summed to provide the solid's moments of inertia about its center of mass.

The Young data were used to obtain right elliptical solid models of all the body segments except the head. A detailed description of the anthropometric measurements used and the approximations and manipulations performed on them to obtain the required model dimensions can be found in Leet (1978b). Even though some redefining cut-planes approximations were made[1], except for the neck[2], the MISEC2 results were within an acceptable 10% of those inertia data measured by Young and his colleagues on the manikins.

The geometric model used for the head is either a homogeneous sphere or an ellipsoid. Anthropometric measurements are usually made of the head's length, width, and depth, and an approximate ellipsoid defined. The principal moments are then computed from the closed-form expressions. The principal axes are naturally coincident with the geometric axes.

We have developed a more novel procedure to obtain the head's principal moments of inertia and principal axes. This procedure is outlined in the following steps:

[1] The end-planes of most of the manikin body segments are not perpendicular to the z-axis. Furthermore, some data were not available, requiring measurements to be made from the available photographs.

[2] The neck segment is a complex geometric shape that will be described later.

1. Determine these head measurements:

   a. Head length. (measured from the middle of the forehead[3], just above the eyebrows, to the middle of the back of the head)

   b. Head breadth. (the maximum breadth of the head)

   c. Head height. (the distance from the chin to the top of the head, in a vertical direction)

   d. Mass. (Homogeneity is still assumed.)

2. Obtain a direction cosine matrix defining the principal axes orientation with respect to a standard local axis system, and the coefficients of the linear equations relating the principal moments computed from the ellipsoid model to the true principal moment values.

3. Use the program "Moments of Inertia of a Rotated Ellipsoid" to compute the principal moments of the head.

The mass in Step 1 can be determined by obtaining the volume value obtained by emersion[4] and multiplying it by a density representative of the class of humans being modeled. For example, Chandler, et al (1975) have determine that the average density for the head segments of six adult male cadavers was 1.056 (SD = .020).

The direction cosine matrix mentioned in Step 2, which defines the orientation of the principal axes, has been determined for the adult male from the Chandler data (Leet, 1978c). This matrix is

$$\begin{bmatrix} 0.6484 & 0.0000 & -0.7613 \\ 0.0000 & 1.0000 & 0.0000 \\ 0.7613 & 0.0000 & 0.6484 \end{bmatrix}$$

The standard local reference system used has its origin at the head's center of mass, with the positive x-axis in the forward direction (It exits the head at about a point midway between the eyes at the level of the eyebrows.), positive y-axis to the right, and positive z-axis straight down, all with the head level and eyes straight ahead. (The technical terminology is "head oriented in the Frankfort plane.") The direction cosine matrix specifies that the principal x-axis is rotated 49.6° counterclockwise about the local reference y-axis: this axis exits the head at about the top of the forehead. (The temptation was to say at the hairline, but that, unfortunately, can be too misleading.) The positive principal z-axis, therefore, exits the head approximately through the mouth.

The "Moments of Inertia of a Rotated Ellipsoid" program uses the three specified head dimensions to define an ellipsoid whose axes are oriented parallel to the local reference axes and centered at the geometric center of the head. It then uses the direction cosine matrix to define a new ellipsoid whose axes are centered at the geometric center, but oriented parallel to the principal axes. The semiaxis lengths for this ellipsoid are taken as the distances from the origin to the intersection of the principal axes with the first ellipsoid. The principal moments of the new ellipsoid are the calculated.

The principal moments obtained by applying this procedure to the six cadaver heads of the Chandler data were linearly correlated with the empirically determined principal moments. There was a high degree of correlation, with the equations being:

$$I_{axx} = 1.98\, I'_{xx} - 82.99 \quad (r^2 = 0.99)$$

$$I_{ayy} = 1.52\, I'_{yy} - 77.66 \quad (r^2 = 0.99)$$

$$I_{azz} = 1.16\, I'_{zz} - 24.22 \quad (r^2 = 0.92)$$

(The experimentally determined moments are I_a and the computed moments are I'.) It is the coefficients of these equations that are referred to in Step 2. The "Moments of Inertia of a Rotated Ellipsoid" program has the capability of performing these linear transformations. A detailed development of this procedure can be found in Leet (1978c).

There is a question about whether or not the specific direction cosine and linear coefficient values can be used for determining the inertia properties of children. However, it seems probable, although not yet proven conclusively, that the mass distribution of the human head is pretty much fixed by the third year. This is the assumption that was made for the three- and six-year-old-child data sets that we generated.

The only inertia property of the head not yet discussed is the center of mass. At present we know of no technique for determining the center of mass of the head from anthropometric data. The values used for the three- and six-year-old-child data sets were the ones determined by Young for the manikins. Edward Becker (1973), at the Naval Aerospace Medical Research Laboratory, has shown that for adult male cadavers, at least, there is only a relatively small variability in the location of the head's center of mass about a mean value of 13 mm in the +x-direction and 21 mm in the -z-direction from the ear hole and midway between the ears.

Techniques Used to Estimate Joint Locations

The body segments in the ATB Model are connected at joints to form the total body. The location of each segment's joints must be defined with respect to the segment's principle axes coordinate system. In general, the segment's cut-planes are

[3] Precise anthropometric terminology exists for all locations mentioned; it can be obtained from the author. It is felt that more common, albeit less precise, terminology is more appropriate for this paper.

[4] The cut-planes between the head and neck defining the head segment are specified in Chandler, et al (1975).

so defined that their centroids are the joint loci.[5] Therefore, the inertia computation process outlined above provides the necessary information to determine the joint locations. However, there are some exceptions. The head-neck joint is located at the mid-point of the line connecting the mastoids (the bone behind the ear). To locate this point with respect to the head's center of mass, anthropometric data must be available relating the center of mass to the mastoids. The neck modeling procedure provided information on the joint's location in the neck.

The neck has a second joint, the upper torso-neck joint. Assuming that it is located the same distance from the back of the neck as the head-neck joint, the coordinates of this joint in the neck can be obtained from the neck modeling procedure. The coordinates of the joint with respect to the centroid of the cut-plane between the neck and upper torso can also be determined. These coordinates can be transferred to the upper torso to provide the joint's location in the upper torso.

The shoulder joints are located using values from the upper arm and upper torso models. The joint is assumed to be one-third of the distance from the top of the shoulder (acromion) to the arm pit (axilla), measured form the acromion. (This fraction is the subject of some controversy.) Details for locating the joint given the anthropometric data on the upper arm and upper torso are provided in Leet (1978b).

The upper torso-mid torso and mid torso-lower torso joint locations are computed using a formula developed by Liu and Wickstrom (1973). With the standard local reference axis system having the positive x-axis forward, the positive y-axis to the right, and the positive z-axis down, the distance in the -x-direction from the center of mass is given by $a_0 + a_1 (W / H * Y))$, where a_0 and a_1 are regression coefficients computed by the authors for each vertebral level, W is the body weight, H is the body height, and Y is the width of the body at the joint location.

The upper torso-mid torso joint is located at about the level of the T7 vertebra. The -x-distance can be computed by averaging the values obtained from the Liu and Wickstrom formula for the T6, T7, and T8 vertebrae. The mid torso-lower torso joint is located at about the level of the L3 vertebra. The -x-distance can be computed by averaging the values obtained from the Liu and Wickstrom formula for the L3, L3, and L4 vertebrae. To complete the coordinate definitions: the y-coordinates for both oints are zero; the z-coordinates can be obtained from the geometric models of the segments.

[5] It is recognized that there is a continuing controversy over rules that locate joints from external landmarks. This issue can not be addressed in this short summary; the results in this paper reflect the latest thinking.

Specification of the hip joint locations requires the geometric model of the lower torso and the anthropometric measurements bispinous breadth (the point of the hip bone in the lower abdomen), which is used to compute the y-coordinate (bispinous breadth/2), the trochanterion height (the hollow on the side of the hip), which is used to compute the z-coordinate (In the geometric model calculations, the center of mass is defined with respect to the top end-plane centroid. Knowledge of the vertical distance from the end-plane, which is the iliocristale height (the very top of the hip bone), to the trochanterion is enough to define the z-coordinate.), and the trochanterion-to-seat-back distance, which is used to compute the x-coordinate.

Techniques Used to Estimate Segment Contact Ellipsoids

The surfaces of the body model are described by the surfaces of ellipsoidal shapes for individual body segments. The present state-of-the-art provides no algorithm for generating the dimensions of these contact ellipsoids; instead, the following set of heuristics is offered. But first it should be pointed out that the segment inertia ellipsoids are independent of the contact ellipsoids. The objective of the contact ellipsoid construction is to provide a surface description for contact force interactions and to generate a representative body shape for graphic display.

The technique used is to work from side and front view photographs of a person representative of the class of individuals being modeled. This person should be in this standard sitting position: the head is oriented in the Frankfort plane, the upper arms are vertical with the palms in, the lower arms are horizontal, the back is straight, the upper legs are horizontal, the lower legs are vertical, and the feet are flat on the floor. The objective here is to position the axes of the body segments parallel to the body reference axes. The outline of the body should be clearly visible in the photographs, and scales close to the body mid-planes should be included. The conditions were met in the Young manikin data.

The body outline and scale are traced on graph paper. The segment cut-planes are drawn on these figures, along with the segment principal axes at the center of mass. At the present time the contact ellipsoid semiaxes are assumed to be oriented parallel to the segment principal axes (The ATB Model program has the option of reorienting the contact ellipsoid semiaxes, but in the present study this reorientation was not required.). The intersections of the segment principal axes with the extreme edges of the segment are used, along with a compass, to locate a first estimate of the contact ellipsoid origins. The coordinates of the origins with respect to the segment principal axes and the semiaxes lengths are supplied to the ATB Model program. This program is run for zero simulation time, followed by a body ellipsoid outline plot program to obtain plots of the initial position of the total body in its environment. Inspection of these plots usually suggested adjust-

ments to the contact ellipsoid dimensions or origin locations.

There is a definite "art" to these heuristics. Furthermore, the iteractive process consumes a comparatively large amount of computer resources and time. Therefore, contact ellipsoid determination is a prime candidate for future procedural improvements.

Techniques Used to Define Body and Joint Axes Orientation

The body orientation in the environment is defined in the ATB Model program by specifying the orientation of the segment principal axes with respect to an inertial reference system and the location of the lower torso segment's center of mass. This is a straightforward procedure and is presented in detail in Leet (1978b).

Two coordinate systems must be defined for each joint, one in each segment associated with the joint. Their relative orientations are used to determine the torque at the joint. A manual procedure used for the three- and six-year-old-child data sets, one that sets the usual initial condition of zero joint torque, is described in detail in Leet (1978b).

3. TECHNIQUES UNDER DEVELOPMENT

Two new geometric models are now under development that should significantly increase the accuracy of the inertia calculations. One of these is a general segment model having up to three parts. One of these parts is the homogeneous right elliptical solid described earlier. The other parts are homogeneous simply-transected elliptical cylinders. A simply-transected elliptical cylinder is an elliptical cylinder that has been cut diagonally from the edge of one end-plane to the opposite edge of the other end-plane. In addition, if a coordinate system is defined with the z-axis passing through the centroids of the end-planes, the cut-plane is parallel to either the x-axis or the y-axis. There can be one simply-transected elliptical cylinder at each end of the right elliptical solid.

The basic procedure for computing the inertial properties of a body segment using this model is:

1. Select one of the following models:
   a. Right elliptical solid
   b. Simply-transected elliptical cylinder
   c. Right elliptical solid with a simply-transected elliptical cylinder at one end
   d. Right elliptical solid with simply-transected elliptical cylinders at each end

2. Define the local coordinate system for each part and a coordinate system for the segment model as a whole.

3. If the model includes a right elliptical solid:
   a. Identify the proximal, mid, and distal planes
   b. Determine the semiaxes for these planes and the distances between them
   c. Determine the density
   d. Run MISEC2

4. For each simply-transected elliptical cylinder:
   a. Determine the base semiaxes and height
   b. Run the program "Simply-Transected Elliptical Cylinders."

5. Combine the individual segment inertia properties using the program "Parallel Axis Theorem."

6. Obtain the segment principal moments and direction cosine matrix using an available eigenvalue and eigenvector program.

Step 2 requires that local coordinate systems be defined for each part of the segment. It is helpful to orient the segment to the rest of the body by defining proximal and distal ends for the segment as a whole and for each of its parts, with the distal end being furthest from the head. Assuming each part has a proximal end-plane, the origins of the local coordinate systems can be located at the proximal end-plane centroids; otherwise, the origin can be located at the distal end-plane centroid. By convention, the orientation of a segment's positive z-axis is along the cylindrical axis, from the proximal end to the distal end. The positive orientation of a segment's y-axis should be right lateral (out the right side). It follows that the positive orientation of a segment's x-axis should be anterior (out the front).

We have developed closed-form expressions for the inertia properties of the simply-transected elliptical cylinder that form the basis for the computer program mentioned in Step 4b. The mathematical manipulations involved were not particularly difficult, but there were numerous opportunities for sign and constant manipulation errors. Therefore, the mathematical results and program will not be released until sample calculations are independently verified by a computer program similar in concept to MISEC2.

The "Parallel Axis Theorem" program in Step 5 has been documented in Leet (1978d) and is available.

The other new geometric model under development is a model of the neck segment. The neck segment is a complex shape. There are two cut-planes between the head and the neck: one is parallel to the Frankfort plane, passing from the back of the head along the base of the skull to a point just behind the ear; the other is parallel to the body reference y-axis and runs from the point just behind the ear tangent to the upper portion of the Adam's apple and out the front of the neck. The

cut-plane between the neck and the upper torso is parallel to the body reference y-axis and passes through the vertebra landmark at the lower back of the neck called the cervicale and a point just above where the two collar bones meet (the suprasternale).

The neck model is comprised of three homogeneous parts: two simply-transected elliptical semicylinders on top of a right elliptical cylinder. A semicylinder is a cylinder that has been bisected along its long, or z-axis, the cut-plane being parallel to either the x- or y-axis. "Simply-transected" means that the semicylinder is transected by a cut-plane that is parallel to the same axis as the bisecting cut-plane and runs from the bisecting cut-plane at one end-plane to the opposite side of the other end-plane in such a way that all the bisecting cut-plane remains. The two simply-transected elliptical semicylinders are stacked on the right elliptical cylinder so that their bisecting cut-planes coincide and their transection cut-planes form the cut-planes between the head and neck. The overall geometric shape closely approximates the neck segment's shape.

Twelve anthropometric measurements, some of them nonstandard, have been defined that can be used to obtain the geometric model dimensions, and a procedure has been developed for converting these into the geometric model. Closed-form expressions for the inertia properties of a simply-transected elliptical semicylinder are currently being derived. As soon as these are available a computer program will be written to convert the anthropometric measurements into the inertia properties.

An interactive FORTRAN program called CIDD is currently being debugged that automates the tedious task of specifying the body segment orientations and the joint axes orientations for the zero torque initial condition. The required input data are the direction angles of each segment with respect to the segment's local reference system and the angles of certain body segments with respect to the inertial reference system. (Generally, only one direction angle per segment is required.) The program leads the user through the required input data by asking simple, completely unambiguous questions. It generates an annotated card deck that can be used directly in the ATB Model program input data deck plus a detailed listing in the same format as is generated by the ATB Model program.

4. CONCLUDING REMARKS

The obvious temptation for any programmer is to create one large interactive program that incorporates all the techniques developed so far, plus techniques that permit easy definition of the environment and contact ellipsoids, perhaps under light-pen or cursor control. Indeed, we are investigating the cost-effectiveness of such a program.

Our research program will have an impact on the sciences of anthropometry and anatomy in a couple of ways. First, the geometric models already developed require some new anthropometric measurements. We have been working closely with experts in these fields to insure that the desired measurements are practical and appropriately defined. Second, if more accurate geometric models of body segments are required, improvement will most likely be made by defining density distributions within segments. No such data currently exist.

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REFERENCES

1. Becker, E.B. (1973), "Measurement of Mass Distribution Parameters of Anatomical Segments", Sixteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, N.Y.

2. Chandler, R.F., C.E. Clauser, J.T. McConville, H.M. Reynolds, and J.W. Young (1975), "Investigation of Inertial Properties of the Human Body", AMRL-TR-74-137, Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH.

3. Fleck, J.T., F.E. Butler, and S.L. Vogel (1974), "An Improved Three-Dimensional Computer Simulation of Motor Vehicle Crash Victims, Volume I Engineering Manual, Volume II Model Validation, Volume III User's Manual, and Volume IV Programmer's Manual", Technical Report No. ZQ-5180-L-1, Calspan Corporation, Buffalo, N.Y.

4. Fleck, J.T. and F.E. Butler, "Development of an Improved Computer Model of the Human Body and Extremity Dynamics (1975)", AMRL-TR-75-14, Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH (1975).

5. Leet, D.G. (1978a), "MISEC2: An Interactive FORTRAN Program That Computes the Inertia Properties of a Homogeneous Right Elliptical Solid", UDR-TR-78-26, University of Dayton Research Institute, Dayton, OH.

6. Leet, D.G. (1978b), "Three- and Six-Year-Old-Child Data Sets for the Articulated Total Body Model. Set I: The Set Developed From the 1976 Young Anthropometric Data", UDR-TR-78-27, University of Dayton Research Institute, Dayton, OH.

7. Leet, D.G. (1978c), "Estimating Moments of Inertia of the Head From Standard Anthropometric Data", UDR-TR-78-28, University of Dayton, Research Institute, Dayton, OH.

8. Leet, D.G. (1978d), "An HP-97 Program That Computes the Inertia Properties of a Segmented, Rigid, Homogeneous Solid From the Inertia Properties of Its Parts", UDR-TR-78-29, University of Dayton Research Institute, Dayton, OH.

9. Liu, Y.K. and J.K, Wickstrom (1973), "Estimation of the Inertial Property Distribution of the Human Torso From Segmented Cadaveric Data", in Perspectives in Biomedical Engineering, R.M. Kenedi (ed.), MacMillian New York, N.Y.

10. Snyder, R.G., L.W. Schneider, C.L. Owings, H.M. Reynolds, D.H. Golomb, and M.A. Schock (1977), "Anthropometric of Infants, Children and Youths to Age 18 for Product Safety Design", UM-HSRI-77-17, Highway Safety Research Institute, Ann Arbor, MI.

11. Young, J.W., H.M. Reynolds, J.T. McConville, R.G. Snyder, and R.F. Chandler (1976), "Development and Evaluation of Masterbody Forms for 3- and 6-Year-Old-Child Dummies", FAA-AM-76-9, FAA Civil Aeromedical Institute, Oklahoma City, OK.

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ABSTRACT

A class of rigid component, chained system models has been developed to predict relative limb and whole body motion of humans during vehicle crashes and aircraft ejection situations. Members of this class include the 3-D Crash Victim Simulator and the Articulated Total Body Model. Both have similar input data requirements, including individual segment inertial properties, joint locations and their biomechanical characteristics, and contact surface definitions. Currently, the only body class for which a significant amount of such data exist is the adult male. In this paper state-of-the-art techniques are presented for generating ATB Model input data sets for two other body classes, the three- and six-year-old child, from anthropometric data. The anthropometric data on these two classes are unique because dental stone manikins have been developed from them that provide various direct inertia and dimensional data for comparison with the corresponding values developed using these techniques.

1. INTRODUCTION AND SUMMARY

Protection of passengers from injury during vehicle and aircraft crashes and the protection of a crew from injury during aircraft ejection situations is one of the important design objectives of vehicle and aircraft design engineers. An increasingly important tool in evaluating the safety aspects of different designs is computer software simulation. Calspan Corporation has developed a particularly sophisticated class of these programs. The class includes the 3-D Crash Victim Simulator (CVS) Model, developed under DOT sponsorship (Fleck, et al, 1974), and the Articulated Total Body (ATB) Model, developed from the CVS Model under the sponsorship of the U.S. Air Force Aerospace Medical Research Laboratories (AMRL) specifically for application to aerospace-type problems (Fleck and Butler, 1975). These programs model the human (or laboratory animal) body as a multisegment chained system. Currently 15 segments are defined: head, neck, upper arm (left and right), lower arm (left and right; includes the hand), upper torso (thoracic region), middle torso (viscera), lower torso (pelvic region), upper leg (left and right), lower leg (left and right), and foot (left and right).

Among the input data required on each segment are:

- inertia properties (mass, center of mass, principal moments, principal axes orientation)
- ellipsoid dimensions, axes origin with respect to the center of mass, and axes orientation with respect to the principal axes
- joint locations with respect to the center of mass, and joint axes orientation (Each joint has two sets of axes, one for each segment associated with the joint. These axes are used to define torques at the joint.)
- various joint stiffness and friction constants

In addition, data must be supplied to define the initial orientation of the body with respect to an external reference coordinate system. The environment (contact planes, restraint systems) must also be defined, as well as remaining initial conditions and the external stimuli to be applied to the system.

The program simulates the dynamics of body motion using a unique method that has been shown to be equivalent to the Lagrange method. Motion picture films of the dynamics can be produced through the use of plot packages supplied with the simulation program.

The University of Dayton Research Institute (UDRI), under the sponsorship of AMRL, is currently involved in a research program to develop input data sets for the ATB Model program. This paper surveys techniques recently developed by the UDRI for obtaining the segment inertia, joint location, and contact ellipsoid data and the initial body orientation. The most direct measurement techniques available for obtaining the segment data involve the use of anthropometric data to define the dimensions of geometric models approximating body segment geometry. The geometric solids, in appropriate combination, have been incorporated into computer programs that generate the required data.

This paper is organized into three parts. Techniques used to generate ATB Model input data sets for 3-year-old and 6-year-old children from anthropometric data are discussed in Section 2.

(Due to their volume, the actual input data sets are not published here. They can be obtained from the author or AMRL.) Some more advanced techniques and programs, still in the development stage, are described in Section 3. The last section discusses directions future efforts are likely to follow.

2. TECHNIQUES USED TO GENERATE ATB MODEL INPUT DATA SETS FOR THE THREE- AND SIX-YEAR-OLD CHILD

The Available Anthropometric Data

The development of ATB Model input data set preparation techniques has emphasized the preparation of data sets for the average three- and six-year-old-child. There are two reasons for emphasing these body classes. The first reason is that these data are needed by the Department of Transportation for auto crash air bag studies. The second is that two anthropometric studies have recently been published that provide detailed anthropometric, inertial and joint location data that can be used to evaluate the data set preparation techniques being developed. One of these studies, performed by Snyder, et al (1977) at the Highway Safety Research Institute (HSRI) under the sponsorship of the Consumer Product Safety Commission, used the latest in automated equipment to obtain and statistically analyze a large sample of standard anthropometric measurements for infants, children, and youths up to age 19. The data are organized by age, are up-to-date, accurate to the state-of-the-art, and copious. The other study was performed by Young, et al (1976) at the Civil Aeromedical Institute under the sponsorship of the Office of Aviation Medicine. In this study, two full-scale dental stone manikins of the average three-year-old and six-year-old were constructed. A number of standard anthropometric measurements available in the literature, along with some nonstandard measurements, were used to construct the manikins. They were constructed in a standard sitting position (to be described later in this paper) and front, side, and rear photographs taken with a ruler scale in view to allow direct determination of dimensions from the photographs. The manikins were segmented and estimates of the centers of mass and some principal moments were made for the segments. Data were also obtained on joints and other landmark locations and specified with respect to each segment's center of mass.

Techniques Used to Generate the Inertia Data

Previous body segment geometric models have been approximated as homogeneous ellipsoids, cylinders, or frustrums of circular cones. The geometric model chosen for our initial modeling effort was a more general shape, a homogeneous right elliptical solid, which has these characteristics:

- It has two parallel elliptical end-planes. A z-axis is defined through the centroids of these end-planes and is normal to both planes.
- The end-planes and any other cross-section parallel to them are ellipses with centers on the z-axis and semiaxes in the xz- or yz-planes.

For our purposes, the shapes of the right elliptical solids to be considered are further restricted to those that can be defined by supplying the semiaxis values of the end-planes and a single cross-section somewhere between the end-planes. Although the other geometric models mentioned have the advantage of having existing closed form expressions for their inertia properties, they are relatively poor approximations to the actual body shape when compared to the right elliptical solids described here.

A very fast interactive FORTRAN program called MISEC2 has been written to compute the inertia properties of the homogeneous right elliptical solid described (Leet, 1978a). The program approximates the solid as a stack of elliptical cylinders of varying semiaxis values, computes the inertia properties of each cylinder, computes the center of mass of the solid as a whole, and then used the parallel axis theorem to shift the individual cylinder's center of rotation to the solid's center of mass, where they are appropriately summed to provide the solid's moments of inertia about its center of mass.

The Young data were used to obtain right elliptical solid models of all the body segments except the head. A detailed description of the anthropometric measurements used and the approximations and manipulations performed on them to obtain the required model dimensions can be found in Leet (1978b). Even though some redefining cut-planes approximations were made[1], except for the neck[2], the MISEC2 results were within an acceptable 10% of those inertia data measured by Young and his colleagues on the manikins.

The geometric model used for the head is either a homogeneous sphere or an ellipsoid. Anthropometric measurements are usually made of the head's length, width, and depth, and an approximate ellipsoid defined. The principal moments are then computed from the closed-form expressions. The principal axes are naturally coincident with the geometric axes.

We have developed a more novel procedure to obtain the head's principal moments of inertia and principal axes. This procedure is outlined in the following steps:

[1] The end-planes of most of the manikin body segments are not perpendicular to the z-axis. Furthermore, some data were not available, requiring measurements to be made from the available photographs.

[2] The neck segment is a complex geometric shape that will be described later.

1. Determine these head measurements:

   a. Head length. (measured from the middle of the forehead[3], just above the eyebrows, to the middle of the back of the head)
   b. Head breadth. (the maximum breadth of the head)
   c. Head height. (the distance from the chin to the top of the head, in a vertical direction)
   d. Mass. (Homogeneity is still assumed.)

2. Obtain a direction cosine matrix defining the principal axes orientation with respect to a standard local axis system, and the coefficients of the linear equations relating the principal moments computed from the ellipsoid model to the true principal moment values.

3. Use the program "Moments of Inertia of a Rotated Ellipsoid" to compute the principal moments of the head.

The mass in Step 1 can be determined by obtaining the volume value obtained by emersion[4] and multiplying it by a density representative of the class of humans being modeled. For example, Chandler, et al (1975) have determine that the average density for the head segments of six adult male cadavers was 1.056 (SD = .020).

The direction cosine matrix mentioned in Step 2, which defines the orientation of the principal axes, has been determined for the adult male from the Chandler data (Leet, 1978c). This matrix is

$$\begin{bmatrix} 0.6484 & 0.0000 & -0.7613 \\ 0.0000 & 1.0000 & 0.0000 \\ 0.7613 & 0.0000 & 0.6484 \end{bmatrix}$$

The standard local reference system used has its origin at the head's center of mass, with the positive x-axis in the forward direction (It exits the head at about a point midway between the eyes at the level of the eyebrows.), positive y-axis to the right, and positive z-axis straight down, all with the head level and eyes straight ahead. (The technical terminology is "head oriented in the Frankfort plane.") The direction cosine matrix specifies that the principal x-axis is rotated 49.6° counterclockwise about the local reference y-axis: this axis exits the head at about the top of the forehead. (The temptation was to say at the hairline, but that, unfortunately, can be too misleading.) The positive principal z-axis, therefore, exits the head approximately through the mouth.

The "Moments of Inertia of a Rotated Ellipsoid" program uses the three specified head dimensions to define an ellipsoid whose axes are oriented parallel to the local reference axes and centered at the geometric center of the head. It then uses the direction cosine matrix to define a new ellipsoid whose axes are centered at the geometric center, but oriented parallel to the principal axes. The semiaxis lengths for this ellipsoid are taken as the distances from the origin to the intersection of the principal axes with the first ellipsoid. The principal moments of the new ellipsoid are the calculated.

The principal moments obtained by applying this procedure to the six cadaver heads of the Chandler data were linearly correlated with the empirically determined principal moments. There was a high degree of correlation, with the equations being:

$$I_{axx} = 1.98\, I'_{xx} - 82.99 \qquad (r^2 = 0.99)$$

$$I_{ayy} = 1.52\, I'_{yy} - 77.66 \qquad (r^2 = 0.99)$$

$$I_{azz} = 1.16\, I'_{zz} - 24.22 \qquad (r^2 = 0.92)$$

(The experimentally determined moments are I_a and the computed moments are I'.) It is the coefficients of these equations that are referred to in Step 2. The "Moments of Inertia of a Rotated Ellipsoid" program has the capability of performing these linear transformations. A detailed development of this procedure can be found in Leet (1978c).

There is a question about whether or not the specific direction cosine and linear coefficient values can be used for determining the inertia properties of children. However, it seems probable, although not yet proven conclusively, that the mass distribution of the human head is pretty much fixed by the third year. This is the assumption that was made for the three- and six-year-old-child data sets that we generated.

The only inertia property of the head not yet discussed is the center of mass. At present we know of no technique for determining the center of mass of the head from anthropometric data. The values used for the three- and six-year-old-child data sets were the ones determined by Young for the manikins. Edward Becker (1973), at the Naval Aerospace Medical Research Laboratory, has shown that for adult male cadavers, at least, there is only a relatively small variability in the location of the head's center of mass about a mean value of 13 mm in the +x-direction and 21 mm in the -z-direction from the ear hole and midway between the ears.

Techniques Used to Estimate Joint Locations

The body segments in the ATB Model are connected at joints to form the total body. The location of each segment's joints must be defined with respect to the segment's principle axes coordinate system. In general, the segment's cut-planes are

[3] Precise anthropometric terminology exists for all locations mentioned; it can be obtained from the author. It is felt that more common, albeit less precise, terminology is more appropriate for this paper.

[4] The cut-planes between the head and neck defining the head segment are specified in Chandler, et al (1975).

so defined that their centroids are the joint loci.[5] Therefore, the inertia computation process outlined above provides the necessary information to determine the joint locations. However, there are some exceptions. The head-neck joint is located at the mid-point of the line connecting the mastoids (the bone behind the ear). To locate this point with respect to the head's center of mass, anthropometric data must be available relating the center of mass to the mastoids. The neck modeling procedure provided information on the joint's location in the neck.

The neck has a second joint, the upper torso-neck joint. Assuming that it is located the same distance from the back of the neck as the head-neck joint, the coordinates of this joint in the neck can be obtained from the neck modeling procedure. The coordinates of the joint with respect to the centroid of the cut-plane between the neck and upper torso can also be determined. These coordinates can be transferred to the upper torso to provide the joint's location in the upper torso.

The shoulder joints are located using values from the upper arm and upper torso models. The joint is assumed to be one-third of the distance from the top of the shoulder (acromion) to the arm pit (axilla), measured form the acromion. (This fraction is the subject of some controversy.) Details for locating the joint given the anthropometric data on the upper arm and upper torso are provided in Leet (1978b).

The upper torso-mid torso and mid torso-lower torso joint locations are computed using a formula developed by Liu and Wickstrom (1973). With the standard local reference axis system having the positive x-axis forward, the positive y-axis to the right, and the positive z-axis down, the distance in the -x-direction from the center of mass is given by $a_0 + a_1 (W / H * Y))$, where a_0 and a_1 are regression coefficients computed by the authors for each vertebral level, W is the body weight, H is the body height, and Y is the width of the body at the joint location.

The upper torso-mid torso joint is located at about the level of the T7 vertebra. The -x-distance can be computed by averaging the values obtained from the Liu and Wickstrom formula for the T6, T7, and T8 vertebrae. The mid torso-lower torso joint is located at about the level of the L3 vertebra. The -x-distance can be computed by averaging the values obtained from the Liu and Wickstrom formula for the L3, L3, and L4 vertebrae. To complete the coordinate definitions: the y-coordinates for both oints are zero; the z-coordinates can be obtained from the geometric models of the segments.

[5] It is recognized that there is a continuing controversy over rules that locate joints from external landmarks. This issue can not be addressed in this short summary; the results in this paper reflect the latest thinking.

Specification of the hip joint locations requires the geometric model of the lower torso and the anthropometric measurements bispinous breadth (the point of the hip bone in the lower abdomen), which is used to compute the y-coordinate (bispinous breadth/2), the trochanterion height (the hollow on the side of the hip), which is used to compute the z-coordinate (In the geometric model calculations, the center of mass is defined with respect to the top end-plane centroid. Knowledge of the vertical distance from the end-plane, which is the iliocristale height (the very top of the hip bone), to the trochanterion is enough to define the z-coordinate.), and the trochanterion-to-seat-back distance, which is used to compute the x-coordinate.

Techniques Used to Estimate Segment Contact Ellipsoids

The surfaces of the body model are described by the surfaces of ellipsoidal shapes for individual body segments. The present state-of-the-art provides no algorithm for generating the dimensions of these contact ellipsoids; instead, the following set of heuristics is offered. But first it should be pointed out that the segment inertia ellipsoids are independent of the contact ellipsoids. The objective of the contact ellipsoid construction is to provide a surface description for contact force interactions and to generate a representative body shape for graphic display.

The technique used is to work from side and front view photographs of a person representative of the class of individuals being modeled. This person should be in this standard sitting position: the head is oriented in the Frankfort plane, the upper arms are vertical with the palms in, the lower arms are horizontal, the back is straight, the upper legs are horizontal, the lower legs are vertical, and the feet are flat on the floor. The objective here is to position the axes of the body segments parallel to the body reference axes. The outline of the body should be clearly visible in the photographs, and scales close to the body midplanes should be included. The conditions were met in the Young manikin data.

The body outline and scale are traced on graph paper. The segment cut-planes are drawn on these figures, along with the segment principal axes at the center of mass. At the present time the contact ellipsoid semiaxes are assumed to be oriented parallel to the segment principal axes (The ATB Model program has the option of reorienting the contact ellipsoid semiaxes, but in the present study this reorientation was not required.). The intersections of the segment principal axes with the extreme edges of the segment are used, along with a compass, to locate a first estimate of the contact ellipsoid origins. The coordinates of the origins with respect to the segment principal axes and the semiaxes lengths are supplied to the ATB Model program. This program is run for zero simulation time, followed by a body ellipsoid outline plot program to obtain plots of the initial position of the total body in its environment. Inspection of these plots usually suggested adjust-

ments to the contact ellipsoid dimensions or origin locations.

There is a definite "art" to these heuristics. Furthermore, the iteractive process consumes a comparatively large amount of computer resources and time. Therefore, contact ellipsoid determination is a prime candidate for future procedural improvements.

Techniques Used to Define Body and Joint Axes Orientation

The body orientation in the environment is defined in the ATB Model program by specifying the orientation of the segment principal axes with respect to an inertial reference system and the location of the lower torso segment's center of mass. This is a straightforward procedure and is presented in detail in Leet (1978b).

Two coordinate systems must be defined for each joint, one in each segment associated with the joint. Their relative orientations are used to determine the torque at the joint. A manual procedure used for the three- and six-year-old-child data sets, one that sets the usual initial condition of zero joint torque, is described in detail in Leet (1978b).

3. TECHNIQUES UNDER DEVELOPMENT

Two new geometric models are now under development that should significantly increase the accuracy of the inertia calculations. One of these is a general segment model having up to three parts. One of these parts is the homogeneous right elliptical solid described earlier. The other parts are homogeneous simply-transected elliptical cylinders. A simply-transected elliptical cylinder is an elliptical cylinder that has been cut diagonally from the edge of one end-plane to the opposite edge of the other end-plane. In addition, if a coordinate system is defined with the z-axis passing through the centroids of the end-planes, the cut-plane is parallel to either the x-axis or the y-axis. There can be one simply-transected elliptical cylinder at each end of the right elliptical solid.

The basic procedure for computing the inertial properties of a body segment using this model is:

1. Select one of the following models:
   a. Right elliptical solid
   b. Simply-transected elliptical cylinder
   c. Right elliptical solid with a simply-transected elliptical cylinder at one end
   d. Right elliptical solid with simply-transected elliptical cylinders at each end

2. Define the local coordinate system for each part and a coordinate system for the segment model as a whole.

3. If the model includes a right elliptical solid:
   a. Identify the proximal, mid, and distal planes
   b. Determine the semiaxes for these planes and the distances between them
   c. Determine the density
   d. Run MISEC2

4. For each simply-transected elliptical cylinder:
   a. Determine the base semiaxes and height
   b. Run the program "Simply-Transected Elliptical Cylinders."

5. Combine the individual segment inertia properties using the program "Parallel Axis Theorem."

6. Obtain the segment principal moments and direction cosine matrix using an available eigenvalue and eigenvector program.

Step 2 requires that local coordinate systems be defined for each part of the segment. It is helpful to orient the segment to the rest of the body by defining proximal and distal ends for the segment as a whole and for each of its parts, with the distal end being furthest from the head. Assuming each part has a proximal end-plane, the origins of the local coordinate systems can be located at the proximal end-plane centroids; otherwise, the origin can be located at the distal end-plane centroid. By convention, the orientation of a segment's positive z-axis is along the cylindrical axis, from the proximal end to the distal end. The positive orientation of a segment's y-axis should be right lateral (out the right side). It follows that the positive orientation of a segment's x-axis should be anterior (out the front).

We have developed closed-form expressions for the inertia properties of the simply-transected elliptical cylinder that form the basis for the computer program mentioned in Step 4b. The mathematical manipulations involved were not particularly difficult, but there were numerous opportunities for sign and constant manipulation errors. Therefore, the mathematical results and program will not be released until sample calculations are independently verified by a computer program similar in concept to MISEC2.

The "Parallel Axis Theorem" program in Step 5 has been documented in Leet (1978d) and is available.

The other new geometric model under development is a model of the neck segment. The neck segment is a complex shape. There are two cut-planes between the head and the neck: one is parallel to the Frankfort plane, passing from the back of the head along the base of the skull to a point just behind the ear; the other is parallel to the body reference y-axis and runs from the point just behind the ear tangent to the upper portion of the Adam's apple and out the front of the neck. The

cut-plane between the neck and the upper torso is parallel to the body reference y-axis and passes through the vertebra landmark at the lower back of the neck called the cervicale and a point just above where the two collar bones meet (the suprasternale).

The neck model is comprised of three homogeneous parts: two simply-transected elliptical semicylinders on top of a right elliptical cylinder. A semicylinder is a cylinder that has been bisected along its long, or z-axis, the cut-plane being parallel to either the x- or y-axis. "Simply-transected" means that the semicylinder is transected by a cut-plane that is parallel to the same axis as the bisecting cut-plane and runs from the bisecting cut-plane at one end-plane to the opposite side of the other end-plane in such a way that all the bisecting cut-plane remains. The two simply-transected elliptical semicylinders are stacked on the right elliptical cylinder so that their bisecting cut-planes coincide and their transection cut-planes form the cut-planes between the head and neck. The overall geometric shape closely approximates the neck segment's shape.

Twelve anthropometric measurements, some of them nonstandard, have been defined that can be used to obtain the geometric model dimensions, and a procedure has been developed for converting these into the geometric model. Closed-form expressions for the inertia properties of a simply-transected elliptical semicylinder are currently being derived. As soon as these are available a computer program will be written to convert the anthropometric measurements into the inertia properties.

An interactive FORTRAN program called CIDD is currently being debugged that automates the tedious task of specifying the body segment orientations and the joint axes orientations for the zero torque initial condition. The required input data are the direction angles of each segment with respect to the segment's local reference system and the angles of certain body segments with respect to the inertial reference system. (Generally, only one direction angle per segment is required.) The program leads the user through the required input data by asking simple, completely unambiguous questions. It generates an annotated card deck that can be used directly in the ATB Model program input data deck plus a detailed listing in the same format as is generated by the ATB Model program.

4. CONCLUDING REMARKS

The obvious temptation for any programmer is to create one large interactive program that incorporates all the techniques developed so far, plus techniques that permit easy definition of the environment and contact ellipsoids, perhaps under light-pen or cursor control. Indeed, we are investigating the cost-effectiveness of such a program.

Our research program will have an impact on the sciences of anthropometry and anatomy in a couple of ways. First, the geometric models already developed require some new anthropometric measurements. We have been working closely with experts in these fields to insure that the desired measurements are practical and appropriately defined. Second, if more accurate geometric models of body segments are required, improvement will most likely be made by defining density distributions within segments. No such data currently exist.

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REFERENCES

1. Becker, E.B. (1973), "Measurement of Mass Distribution Parameters of Anatomical Segments", Sixteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, N.Y.

2. Chandler, R.F., C.E. Clauser, J.T. McConville, H.M. Reynolds, and J.W. Young (1975), "Investigation of Inertial Properties of the Human Body", AMRL-TR-74-137, Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH.

3. Fleck, J.T., F.E. Butler, and S.L. Vogel (1974), "An Improved Three-Dimensional Computer Simulation of Motor Vehicle Crash Victims, Volume I Engineering Manual, Volume II Model Validation, Volume III User's Manual, and Volume IV Programmer's Manual", Technical Report No. ZQ-5180-L-1, Calspan Corporation, Buffalo, N.Y.

4. Fleck, J.T. and F.E. Butler, "Development of an Improved Computer Model of the Human Body and Extremity Dynamics (1975)", AMRL-TR-75-14, Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH (1975).

5. Leet, D.G. (1978a), "MISEC2: An Interactive FORTRAN Program That Computes the Inertia Properties of a Homogeneous Right Elliptical Solid", UDR-TR-78-26, University of Dayton Research Institute, Dayton, OH.

6. Leet, D.G. (1978b), "Three- and Six-Year-Old-Child Data Sets for the Articulated Total Body Model. Set I: The Set Developed From the 1976 Young Anthropometric Data", UDR-TR-78-27, University of Dayton Research Institute, Dayton, OH.

7. Leet, D.G. (1978c), "Estimating Moments of Inertia of the Head From Standard Anthropometric Data", UDR-TR-78-28, University of Dayton, Research Institute, Dayton, OH.

8. Leet, D.G. (1978d), "An HP-97 Program That Computes the Inertia Properties of a Segmented, Rigid, Homogeneous Solid From the Inertia Properties of Its Parts", UDR-TR-78-29, University of Dayton Research Institute, Dayton, OH.

9. Liu, Y.K. and J.K, Wickstrom (1973), "Estimation of the Inertial Property Distribution of the Human Torso From Segmented Cadaveric Data", in <u>Perspectives in Biomedical Engineering</u>, R.M. Kenedi (ed.), MacMillian New York, N.Y.

10. Snyder, R.G., L.W. Schneider, C.L. Owings, H.M. Reynolds, D.H. Golomb, and M.A. Schock (1977), "Anthropometric of Infants, Children and Youths to Age 18 for Product Safety Design", UM-HSRI-77-17, Highway Safety Research Institute, Ann Arbor, MI.

11. Young, J.W., H.M. Reynolds, J.T. McConville, R.G. Snyder, and R.F. Chandler (1976), "Development and Evaluation of Masterbody Forms for 3- and 6-Year-Old-Child Dummies", FAA-AM-76-9, FAA Civil Aeromedical Institute, Oklahoma City, OK.